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SPACE-TIME CHARACTERISTICS OF THE FIELD OF LONG-WAVE RADIATION IN THE ATMOSPHERE

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16. Abstract

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SPACE-TIME CHARACTERISTICS OF THE FIELD OF LONG-WAVE RADIATION IN THE ATMOSPHERE

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A field of long-wave radiation, as most other meteorological parameters of the atmosphere, undergoes regular variations during the year. Such variations are revealed in the form of deviations from the average state, the features of which are discussed in [2]. Continuing the analysis, we will stop at the properties of the finer structure of the radiation field, corresponding to separate seasons of the year. The results of actinometric radio sounding for the years 1963 - 1967 [2] were used as factual material; they were averaged for four seasons: winter (December - February), spring (March - May), summer (June - August), and fall (September - October).

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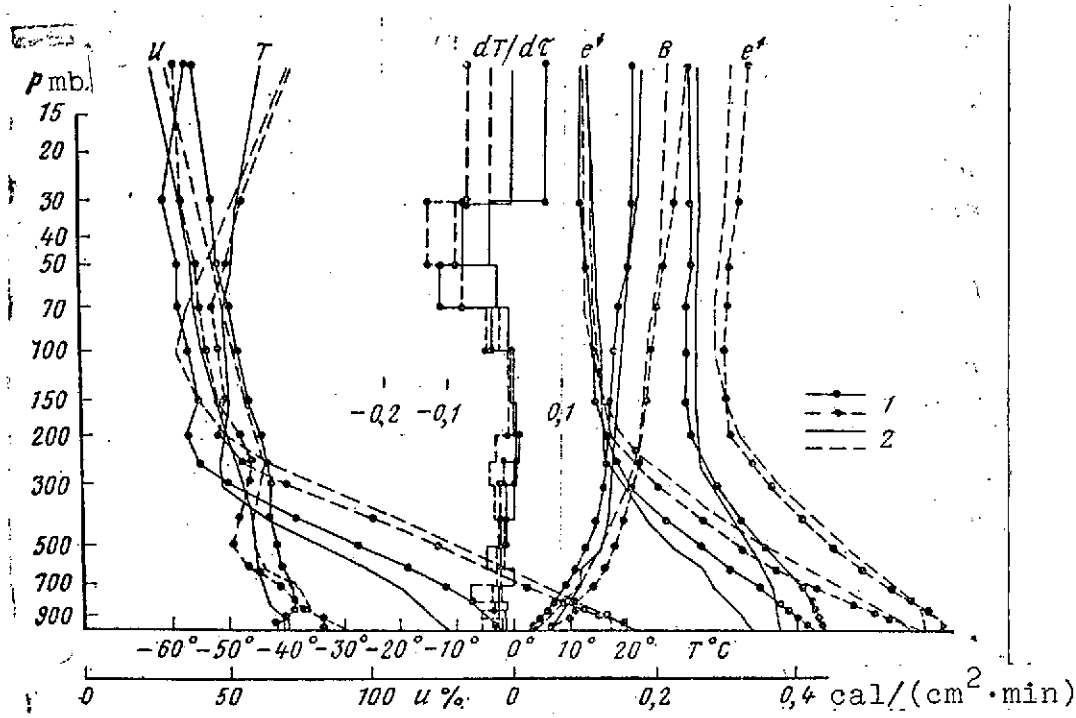

Figure 1. Summer (dotted line) and winter (solid line) profiles of parameters T, u, $^{\uparrow}e$, $^{\downarrow}e$, B and dT/dτ at stations Kiev (1) and Vladivostok (2) for 1963 - 1967

Figure 1 shows the summer and winter average vertical profiles of parameters T, u, $e^{\uparrow}$, $e^{\downarrow}$, B and dT/dτ for each station; Figure 2 shows the curves of seasonal variations for parameters $e^{\uparrow}$ and $e^{\downarrow}$. Yearly amplitudes $e^{\uparrow}$ and $e^{\downarrow}$, obtained as the difference of "summer-winter" are shown in Tables 2 and 3.

As seen from the given material, the amplitude of seasonal variations $e^{\uparrow}$ and $e^{\downarrow}$ significantly decreases with height, and seasonal variations of long-wave radiation balance, on the other hand, increase with height. The maximum values of ascending and descending radiative fluxes and also, in most cases, the radiation balance of the Earth-atmosphere system, are observed in summer, whereas the minimal are observed in winter. On the average, the radiation balance of the Earth-atmosphere system is higher by 0.06 cal/(cm^2 · min) in summer than in winter. Typically, the amplitudes of seasonal variations for the descending flux decrease more rapidly with height than the ascending, which confirms the greater stability of $e^{\downarrow}$ in the stratosphere [2]. Significant stability is also revealed in the yearly amplitudes of the radiative fluxes from year to year. The same is true with respect to air temperature.

Ascending flux ($e^{\uparrow}$) near the ground is entirely determined by the radiation of the Earth's surface and, therefore, the magnitude of $e^{\uparrow}$ at the Earth's surface corresponds everywhere to its temperature. In the summer it lies within 0.512 to 0.630 cal/(cm^2 · min); in winter, $e^{\uparrow}$ decreases by approximately 1.5 times, and varies from 0.340 to 0.484 cal/(cm^2 · min). In winter, the variations of $e^{\uparrow}$ are greater /68 from station to station than in summer, since the horizontal temperature gradients of the underlying surface are greater in winter than in summer, and the snow cover is not absolute.

At the 50 mb level (in the central stratosphere), the ascending flux varies along the territory from 0.262 to 0.305 cal/(cm^2 · min). Thus, in summer $e^{\uparrow}$ and its variations in the stratosphere from station to station are twice as small as at the ground level (approximately 0.5 $e_0^{\uparrow}$). In winter, the ascending flux in the stratosphere is approximately 0.6 $e_0^{\uparrow}$, and is within the limits of 0.220 to 0.260 cal/(cm^2 · min). However, the variations of $e^{\uparrow}$ over the territory are the same as in summer.

As shown in Table 1, the vertical gradients of ascending flux $\gamma_{e^{\uparrow}}$ in winter (in dry and cold atmospheres) are smaller than in summer (in warm and damp atmospheres). The average gradient $\gamma_{e^{\uparrow}}$ in the troposphere is equal to 0.023 - 0.031 cal/(cm^2 · min) at 1 km in the summer, whereas in winter it is only 0.010 - 0.020 cal/(cm^2 · min) at 1 km. In the lowest stratum of the troposphere, $\gamma_{e^{\uparrow}}$ is also two times or more smaller than in summer. In winter, over a snow-covered

TABLE 1. VERTICAL GRADIENTS OF $\gamma_{e\uparrow}$ AND $\gamma_{e\uparrow}$ IN SUMMER AND WINTER, cal/(cm^2 · min) AT 1 km

Stratum, mb	Riga		Kiev		Vladivostok	
	$\gamma_{e\uparrow} \cdot 10^3$	$\gamma_{e\downarrow} \cdot 10^3$	$\gamma_{e\uparrow} \cdot 10^3$	$\gamma_{e\downarrow} \cdot 10^3$	$\gamma_{e\uparrow} \cdot 10^3$	$\gamma_{e\downarrow} \cdot 10^3$
Summer						
1000—800	2	26	15	45	6	25
800—500	27	41	31	43	26	40
500—200	23	29	24	30	24	32
200—100	0	3	2	4	9	10
100—30	0	2	—2	2	—1	2
Winter						
1000—800	9	29	4	24	3	20
800—500	20	33	19	33	10	23
500—200	16	21	18	23	16	20
200—100	0	3	2	3	1	3
100—50	0	3	0	3	0	2

surface, inversions of air temperature develop and, as a consequence, their influence on $\gamma_{e\uparrow}$ decreases. In summer, as shown in Figure 1, a sharper break in the vertical profile of $e^{\uparrow}$ at the level of the tropopause is noticeable, than is the case in winter. Seasonal variations in the stratosphere in various regions characterize the integral absorbing and radiative capabilities of the Earth and troposphere as a whole, and their effective values of temperature and humidity.

Descending flux ($e^{\downarrow}$), which characterizes oncoming radiation in various air masses, varies at the ground level in summer from 0.495 - 0.580 cal/(cm^2 · min), and winter - 0,307 - 0,450 cal/(cm^2 · min). For this the maximum values of $e^{\downarrow}$ at the ground level were noted at the southern station (Tbilisi, Rostov, Kiev), and also at stations where significant frequency of cloudiness was observed.

In the stratosphere at the 50 mb level, $e^{\downarrow}$ varies in summer from 0.082 to 0.105 cal/(cm^2 · min), and in winter from 0.076 to 0.101 cal/(cm^2 · min). Thus, several seasonal and spatial variations /69

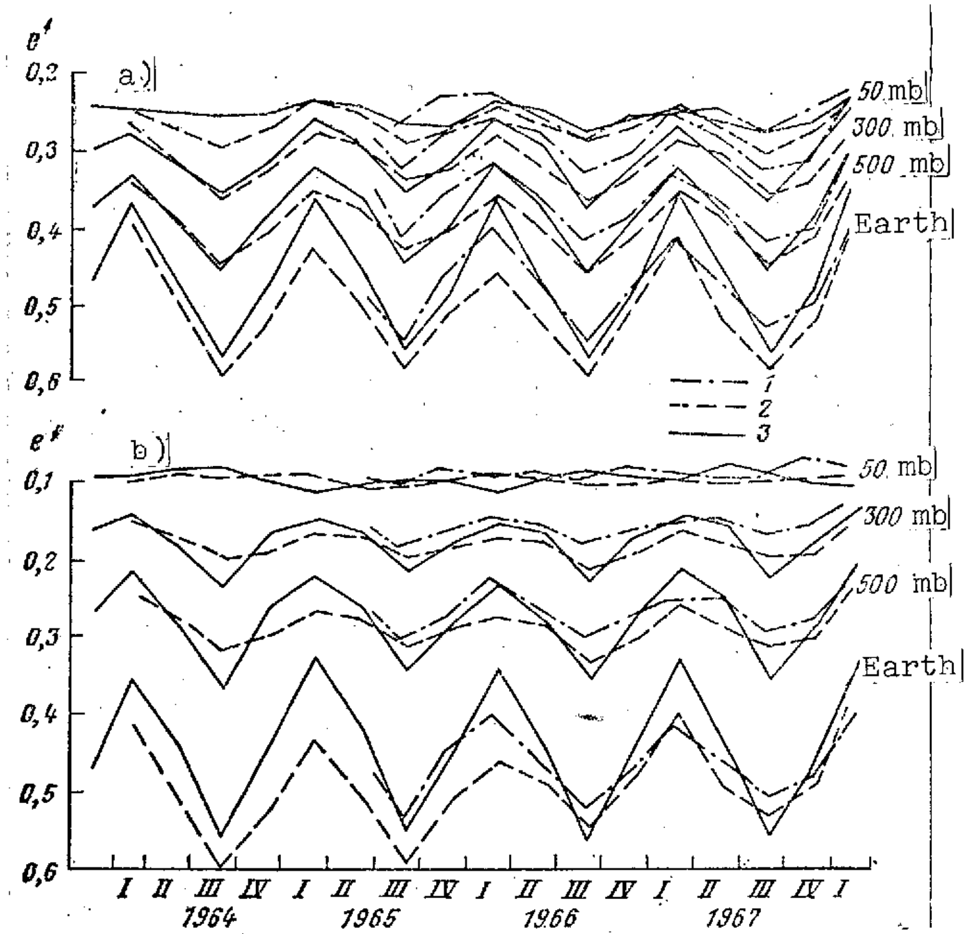

Figure 2. Seasonal variations in ascending (a) and descending (b) fluxes of long-wave radiation at stations Riga (1), Kiev (2), and Vladivostok (3) at various barometric levels

are noticeable in this flux. In winter, e is somewhat smaller than in summer. However, the limits of variations in the descending flux in the territory are greater in winter than in summer. This is also true of the ascending flux.

Table 1 shows that the vertical gradient of the descending flux exceeds, in almost all cases, the vertical gradient of the ascending flux, which is also true of the mean annual profile [2]. Besides this, vertical variations of $e^{\downarrow}$ occur more rapidly in summer than in winter. Thus, in the lower troposphere $\gamma_{e\downarrow}$ in summer is equal to 0.040 cal/(cm^2 · min) at 1 km, and in winter is equal to 0.030

TABLE 2. YEARLY AMPLITUDES OF ASCENDING (NUMERATOR) AND DESCENDING (DENOMINATOR) FLUXES (DIFFERENCE SUMMER-WINTER) IN $\Delta e^{\uparrow}$ AND $\Delta e^{\downarrow} \cdot 10^3$ cal/(cm^2 · min)

Designated stations	Level, mb												
	Earth	850	700	600	500	400	300	250	200	150	100	70	50
Dolgoprudnaya	151/136	140/112	108/82	93/66	85/57	76/43	69/31	62/24	57/17	57/12	57/16	57/22	57/24
Minsk	144/110	141/107	111/84	98/72	91/64	84/52	80/36	62/24	51/11	44/6	48/3	47/−1	50/−3
Rostov	173/143	154/117	116/77	101/60	91/45	84/34	77/24	75/17	56/9	62/4	56/1	46/1	54/−5
Sverdlovsk	179/166	174/143	164/100	116/76	104/60	94/46	85/32	81/25	71/16	69/13	66/13	67/13	67/13
Vladivostok	204/219	201/203	177/181	153/146	135/135	118/113	99/80	86/58	62/27	40/5	26/−11	27/−14	31/−16
Aralsk	234/211	197/171	147/92	120/66	106/58	96/36	94/22	90/12	94/10	88/5	50/−6	49/−8	55/−1
Bezenchuk	181/140	176/130	132/87	105/67	97/50	91/39	83/27	76/20	67/11	78/7	66/9	66/7	66/14
Voyekovo	158/132	153/117	131/91	131/75	114/71	105/56	96/35	73/21	57/5	59/3	62/3	64/3	68/2
Riga	135/114	134/107	113/81	104/76	75/60	86/52	74/33	64/18	47/5	47/3	47/6	40/11	47/11
Tbilisi	142/115	137/114	111/92	101/81	83/59	75/43	83/33	77/29	74/24	59/10	39/−4	39/−17	41/−19
Petropavlovsk-Kamchatsky	145/151	133/138	128/129	118/118	109/103	96/87	84/66	73/51	47/20	29/0	27/−5	32/−10	24/−8
Yuzhno-Sakhalinsk	171/187	161/203	154/186	143/165	129/139	116/112	89/75	75/55	44/23	39/14	16/3	18/−2	26/−1
Kiev	165/146	156/119	120/81	107/68	97/60	88/53	77/37	70/26	57/10	56/7	54/5	57/5	54/7

TABLE 3. VARIATION LIMITS OF HORIZONTAL GRADIENT OF ASCENDING FLUX AT VARIOUS LEVELS IN THE ATMOSPHERE, cal/(cm^2 · min) AT 100 KM*

Season	Level, mb		
	970	500	100
Winter	0,003—0,010	0,002—0,006	0,000—0,003
Summer	0,001—0,009	0,000—0,005	0,000—0,002
Year	0,004—0,012	0,002—0,008	0,001—0,003

*Commas represent decimal points.

cal/(cm^2 · min) at 1 km. However, up to 35 km altitudes, strata having systematic increases of $e^{\downarrow}$ with height [4] are not observed with in winter or in summer.

The balance of long-wave radiation of the Earth-atmosphere system (B) is negative, and varies in summer at ground level along the territory from 0.020 to 0.050 cal/cm^2 · min). Its minimal values are equal to 0.018 - 0.021 cal/(cm^2 · min), observed in Vladivostok, Yuzhno-Sakhalinsk and Riga, whereas the maxima are observed in Bezenchuk, Minsk, Rostov and Tbilisi. In winter, the value of B_0 lies within the limits of 0.005 to 0.030 cal/(cm^2 · min). In most stations at all levels of the atmosphere, the balance is greater in summer than in winter; B in the troposphere remains the same from summer to winter only at the coastal far-east stations (Vladivostok, Petropavlovsk-Kamchatsky and Yuzhno-Sakhalinsk) (Figure 1), and at Yuzhno-Sakhzlinsk in the lower troposphere, the winter values of B are even larger than summer values by 0.020 - 0.040 cal/(cm^2 · min). The /70 radiation balance increases with height both in summer and in winter. In the stratosphere, the limits of variation in summer are equal from 0.190 to 0.224 cal/(cm^2 · min), and in winter from 0.140 to 0.160 cal/(cm^2 · min).

The speed of variation in air temperature (dT/dτ) was calculated by the vertical profile of the radiation balance (Figure 1). Clear regularities in the variation of dT/dτ from winter to summer were not observed. However, in most cases, in the higher troposphere (600 - 300 mb) radiative cooling was greater in summer than in winter. The average values of dT/dτ in this stratum in summer are 0.035 - 0.045 °C/hr, and in winter are only 0.025 - 0.035 °C/hr. In Vladivostok, these differences are greater, since the radiation balance, according to the station's data, increases in summer up to altitudes of 10 - 11 km (200 mb), and in winter — only to 5 - 6 km (450 mb). This data is in accordance with the fact that water-droplet clouds (summer) are more active with respect to radiation than crystalline clouds [1].

At the level of the troposphere, $dT/d\tau$ decreases in all cases, both in summer and winter, but in summer cooling is twice as great (-0.020 - 0.030 °C/hr) than in winter (-0.010 - 0.015 °C/hr). From this it follows that in the tropopause, the frequency of cases of radiation heating is greater in winter than in summer. In the stratosphere, radiation cooling with height is also greater in summer than in winter. /71

For a more detailed characterization of seasonal variations in the radiative field, Figure 2 and Table 2 show seasonal variations of $e^{\uparrow}$ and $e^{\downarrow}$, and yearly amplitudes of ascending and descending radiative fluxes. In Vladivostok and Aralsk, maximal amplitudes of ascending flux — 0.204 - 0.234 cal/(cm^2 · min), respectively — are observed. Significant amplitudes are also observed at the continental stations, Sverdlovsk and Bezenchuk. At stations located in more moderate climates, the yearly amplitude of $e^{\uparrow}$ decreases, and its minimal value, equal to 0.135 cal/(cm^2 · min), is observed at Riga. Thus, the maximal difference in yearly amplitudes ($\Delta e^{\uparrow}$) at ground level is approximately 0.100 cal/(cm^2 · min); it decreases with height, and already at 250 mb level (under the tropopause), the maximal difference is equal only to 0.028 cal/(cm^2 · min). In the stratosphere, however, at all three far-eastern stations (Vladivostok, Yuzhno-Sakhalinsk and Petropavlovsk-Kamchatsky), minimal values of $\Delta e^{\uparrow}$ are observed. The reason for this may be found by comparing the temperature profiles of air and humidity in the Far East and in ETS (European Temperature Stations) (Figure 1). Due to monsoon circulation of the atmosphere in the Far East, seasonal oscillations of temperature and humidity in the higher atmosphere are substantially smaller than at continental stations.

Climatic peculiarities of particular regions are also revealed in the analysis of yearly amplitudes of descending flux of radiation ($\Delta e^{\downarrow}$) (Table 2). As with $\Delta e^{\uparrow}$, the amplitude of descending flux decreases with height, but significantly faster. At ground level, the maximal values of $\Delta e^{\downarrow}$ are also observed at Aralsk (0.211) and at Vladivostok (0.219); minimal values are observed at Minsk, Riga, Tbilisi (0.110 - 0.115). Peculiarities of the monsoon climate are revealed even more clearly. Thus, at the 100 - 300 mb level, $\Delta e^{\downarrow}$ at three far eastern stations is two or more times greater than at other stations, and levels out only at the 150 - 200 mb level. In the stratosphere, the summer values for descending flux become smaller than winter values. This phenomenon cannot be considered as a random one. Table 2 shows that negative differences summer-winter are also observed at a whole series of stations located in the south (Minsk, Rostov, Aralsk and Tbilisi.

The noted seasonal evolution of descending flux is the consequence of seasonal variations in radiative absorption in the lower stratosphere. Inasmuch as ozone is the main absorbing gas at the altitudes under consideration, the seasonal variations of descending flux should correspond to variations in density of the ozone stratum; particularly, the optic mass of ozone should be smaller in summer than in winter. Ozonometrical data is in complete accordance with this conclusion [3]. Inasmuch as stratospheric ozone is conserved, all the properties of the ozone stratum, including its density, are determined by the peculiarities of atmospheric circulation. The existence of a single-valued dependence between radiation and ozone variations, and also the simultaneous presence of a dependence between the ozone field and circulation, permit us to conclude that a dependence exists between variations of long-wave radiation and atmospheric currents at corresponding altitudes. Such a peculiarity can serve as an example of the feedback, which is rather a general property of the atmosphere.

We will consider the general properties of the standard deviations $\sigma_{e\uparrow}$ and $\sigma_{e\downarrow}$. On the average, for all stations, $\sigma_{e\uparrow}$ and $\sigma_{e\downarrow}$ are smaller in summer than in winter, although the difference is small. In the lower troposphere, $\sigma_{e\uparrow}$ on the average is equal to

0.040 cal/(cm^2 · min), and $\sigma_{e\downarrow}$ is equal to 0.030 cal/(cm^2 · min). Standard deviations decrease with height, which is natural since the most significant non-periodic oscillations of fluxes are caused by cloudiness. In the higher troposphere, $\sigma_{e\uparrow}$ is equal to 0.025 cal/(cm^2 · min), and $\sigma_{e\downarrow}$ is equal to 0.020 cal/(cm^2 · min). In the stratosphere, $\sigma_{e\uparrow}$ is almost twice as great as $\sigma_{e\downarrow}$ ($\sigma_{e\downarrow}$ = 0.013, $\sigma_{e\uparrow}$ = 0.025).

In the analysis of spatial distribution of mean long-term values of ascending flux of long-wave radiation [2], the connection between variation of radiation fields and climatic peculiarities of separate regions was noted. The influence of climate appears even more clearly on seasonal charts (Figure 3). Since at ground level $e^{\uparrow}$ is almost totally determined by its temperature, the horizontal gradients of $e^{\uparrow}$ are, on the average, greater in winter than in summer (Table 3). However, the snow line, which is near the 52nd parallel, may play a role here.

During the transition from winter to summer, the magnitude and the direction of the horizontal gradients of $e^{\uparrow}$ undergo substantial change. Figure 3 shows that between the 45th and 64th parallels, the isolines in winter go from northwest to southeast, and only below the 45th parallel (the Caucasus) do they develop a parallel direction. In summer the isolines of $e^{\uparrow}$ in the central regions follow the parallels, and in the southern region they go from southwest to northeast. Apparently, the ground field of ascending flux radiation is determined by these same processes of atmospherical circulation and by the inflow of solar heat, which simultaneously shape the temperature field at the ground level. /74

At 500 mb altitudes, horizontal gradients decrease both in winter and in summer, and the direction of the isoline changes. In winter, the isolines take parallel directions with increased height. This is caused by the simultaneous influence of two factors: in the east, the winter radiation of the Earth's surface is smaller than in the west, but absorption of this radiation by the cold dry atmosphere is also smaller. In summer, the directions of the isolines $e^{\uparrow}$ do not change with height, inasmuch as in the southeast the radiation of the Earth's surface is greater, but the influence of a dry atmosphere is less. Therefore, at the 500 mb level, the maximal values of $e^{\uparrow}$ are observed in the southeast, just as at ground level.

In the Byellorussian-Baltic regions at levels of 500 and 100 mb, due to the screening effect of cloudiness, the horizontal gradient of ascending flux is practically absent in summer, and the paths of

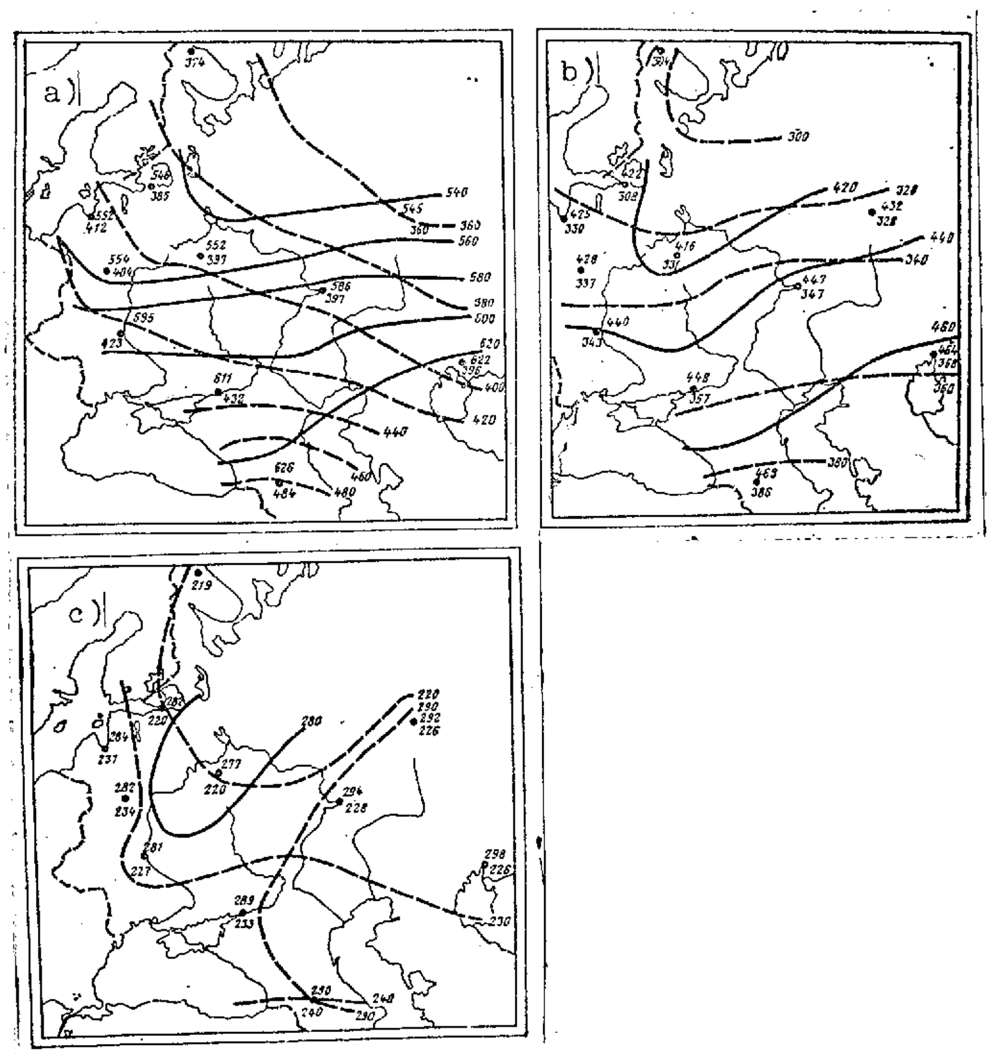

Figure 3. Distribution of mid-season magnitudes $e^{\uparrow} \cdot 10^3$ cal/(cm^2 · min) in ETS territory in summer (solid lines) and winter (dotted lines):
a — 970 mb; b — 500 mb; c — 100 mb

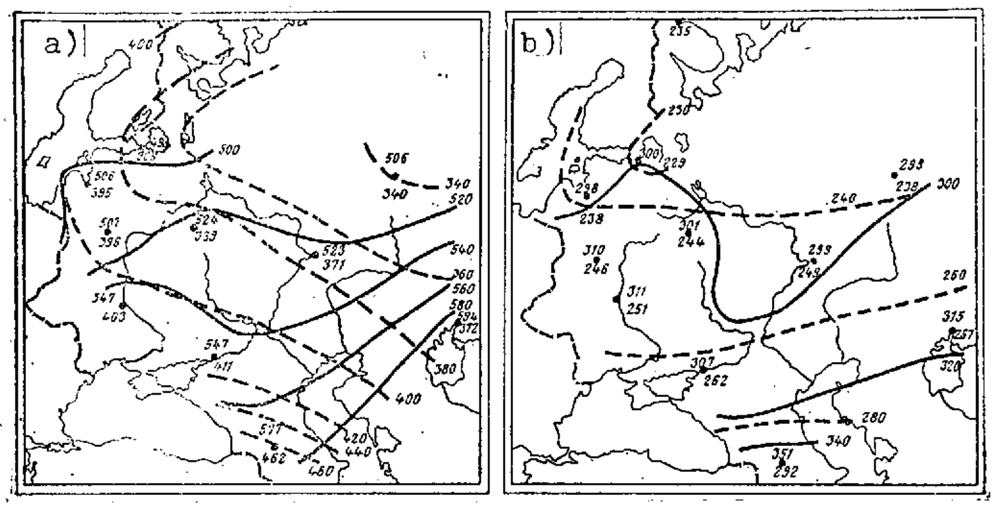

Figure 4. Distribution of mid-season magnitudes $e^{\downarrow} \cdot 10^3$ cal/(cm^2 · min) in ETS territory in summer (solid lines) and winter (dotted lines):
a — 970 mb; b — 500 mb

isolines $e^{\uparrow}$ are not in accordance with the paths of the isotherms at this level. In summer at the 100 mb level, the gradients of the ascending radiation flux are directly opposite to the horizontal gradients of the temperature field. The air temperature at the 100 mb level decreases in the direction from northwest to southeast, and the ascending flux is maximal at the southeast and minimal at the northwest. All this can be explained by the fact that in summer the main source of ascending radiation flux in the higher strata are water droplet cumulus clouds and cumulonimbus clouds, whose tops are /75
located between 500 and 100 mb levels. Because of the radiation screening effect of these clouds, the temperature of the higher-lying strata decreases [3].

The spatial variations of the descending flux and of the radiation balance are significantly smaller than the variations of the ascending flux (Figure 4). The main factor which influences the magnitude of descending flux near the Earth's surface is the properties of air masses. In Sverdlovsk, the average yearly value of $e^{\downarrow}$ is 0.050 cal/(cm^2 · min) less than in Riga (Figure 4), as a consequence of the fact that at Sverdlovsk (in the center of the continent), the continental air masses have lower temperature and humidity for the greater part of the year. The cloudiness in Riga averages 8.3 on the scale of cloudiness, and only 7.1 in Sverdlovsk.

From winter to summer, $e^{\downarrow}$ varies within smaller limits than $e^{\uparrow}$ (Figure 4). $\Delta e^{\downarrow}$ decreases rapidly with height and at 100 mb level for the duration of the whole year remains practically unchanged. Spatial differences in descending fluxes at the 100 mb level are insignificant both in summer and in winter, which is evidence of minor seasonal oscillations of the absorbing and radiating components of the higher atmosphere.

The spatial variations of radiation balance change significantly less during the year than their components — ascending and descending fluxes. This indicates that long-wave radiation makes a practically constant contribution to variations in air temperature during the year.

References

1. Gaevsky, V. L. Profile of Fluxes of Long-Wave Radiation in Clouds). Collection: Issledovaniye oblakov, osadkovii grozovogo elektrichestva (Investigation of Clouds, Precipitation, and Thunderstorm Activity). Academia Nauk SSSR, 1961.

2. Zaytseva, N. A., G. N. Kostianoy and V. I. Shlyakhov. Sredniye mnogoletniye kharakteristiki polya dlinovolnovoy radiatsii (po dannim seti ARZ) [Average Long-Term Characteristics of Long-Wave Radiation Fields (Data of ARZ Network)]. Meteorology and Hydrology, No. 7, 1971.

3. Khrgyan, A. Kh. Fizika atmosfery (Physics of the Atmosphere). Gidrometeoizdat, Leningrad, 1969.

4. Mueller, H. G. Radiation Measurements in the Free Atmosphere During the IGY and IGC. Annals of IGY, Vol. 32, 1964.

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